

What is claimed:

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1. A vibratory system for moving a driven element, comprising:  
a vibratory element having a driving element in driving communication with a resonator that has a selected contacting portion located to engage the driven element during use of the system, the vibrating element and resonator being configured to move the selected contacting portion in a first elliptical motion when the resonator is excited to simultaneously resonate in at least two vibration modes by a first signal at a first frequency provided to the vibrating element, the resulting motion being of sufficient amplitude to move the driven element when the driven element and selected contacting portion are maintained in sufficient contact to achieve a desired motion of the driven element, the at least two vibration modes being selected so that at least one does not include a pure longitudinal or bending mode of the resonator to produce the first elliptical motion.
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2. The vibratory system of Claim 1, wherein driving element comprises a piezoelectric element.
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3. The vibratory system of Claim 2, wherein the piezoelectric element and resonator are configured to cause the selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency provided to the piezoelectric element.
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4. The vibratory system of Claim 2, wherein the vibration mode produces a node on the resonator element at the first frequency, and further comprising a resilient mounting connected to the vibratory element at the node and located to resiliently urge the vibratory element against the driven element during operation of the system.
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5. The vibratory system of Claim 2, wherein the vibration mode produces a node on the vibratory element and further comprising a resilient mounting connected to the vibratory element at a location other than the node and located to resiliently urge the vibratory element against the driven element during operation of the system.
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6. The vibratory system of Claim 2, wherein the piezoelectric element is held in compression in the resonator during operation of the system.
7. The vibratory system of Claim 2, wherein the piezoelectric element is press-fit into an opening in the resonator to place the piezoelectric element in compression during operation of the system.

8. The vibratory system of Claim 2, wherein the piezoelectric element is held in compression by walls of the resonator that are stressed past their yield point, during operation of the system.
9. The vibratory system of Claim 3, wherein the first elliptical motion has a major and minor axis, and the second elliptical motion has a major and minor axis, with the ratio of the major to minor axes being in the range of about 3:1 to 150:1.
10. The vibratory system of Claim 2, wherein one of the elliptical motions has a major and minor axis with one of the major and minor axes being aligned with a tangent to the driven element at the selected contacting portion and along the direction of motion.
11. The vibratory system of Claim 8, wherein the vibration mode produces a node on the vibratory element and further comprising a resilient mounting connected to the vibratory element at a location other than the node and located to resiliently urge the vibratory element against the driven element during operation of the system.
12. The vibratory system of Claim 2, wherein the piezoelectric element is held in compression by walls of the resonator and wherein the walls are curved.
13. The vibratory system of Claim 3, wherein the piezoelectric element is held in compression by walls of the resonator and wherein at least one of the walls is curved.
14. The vibratory system of Claim 2, further comprising a resilient element interposed between a base and the vibratory element, and configured relative to the vibratory element to resiliently urge the vibratory element against the driven element during operation of the system.
15. The vibratory system of Claim 8, further comprising a resilient element interposed between a base and the vibratory element, and configured relative to the vibratory element to resiliently urge the vibratory element against the driven element during operation of the system.
16. The vibratory system of Claim 3, wherein the first elliptical motion has a major axis inclined at an angle with respect to a predominant axis of the vibratory element so as to more closely align the major axis with the direction of motion of the driven element during use of the system, the system configuration and angle of inclination being selected so that an angle  $\beta$  between the major axis and a tangent to the driven element at the selected contacting portion and along the direction of motion, varies by about 25 degrees or less over a frequency range of about 200 Hz or greater, on either side of the first frequency.

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17. The vibratory system of Claim 16, wherein the angle  $\beta$  varies by about 10 degrees or less.
18. The vibratory system of Claim 2 wherein the first elliptical motion has one of its major and minor axes inclined at an angle  $\beta$  with respect to a tangent to the driven element at the selected contacting portion and along a direction of motion of the driven element, and the angle  $\beta$  being between about 5-35 degrees or 55-85 degrees when the selected contacting portion is drivingly engaging the driven element.
- 5 19. The vibratory system of Claim 8, wherein the first elliptical motion has one of its major and minor axes inclined at an angle  $\beta$  with respect to a tangent to the driven element along the direction of motion of the driven element at the selected contacting portion, the angle  $\beta$  being between about 5-35 degrees or 55-85 degrees when the selected contacting portion is drivingly engaging the driven element.
- 10 20. The vibratory system of Claim 8, wherein the piezoelectric element has an inclined surface adjacent an edge of the piezoelectric element which was used to press-fit the piezoelectric element into an opening in the resonator.
- 15 21. The vibratory system of Claim 8, wherein there are a plurality of vibrating elements each having a selected contacting portion resiliently urged against a common driven element.
- 20 22. The vibratory system of Claim 2, wherein the selected contacting portion is in contact with the driven element and the piezoelectric element generates a vibratory signal detected by a sensor in communication with the driven element, and where the time between the generation and receipt of the signal is representative of the position of the driven element relative to the vibrating element.
- 25 23. The vibratory system of Claim 2, wherein the selected contacting portion is in contact with the driven element and the piezoelectric element receives a vibratory signal provided a device in communication with the driven element, and where the time between the generation and receipt of the signal is representative of the position of the driven element relative to the vibrating element.
- 30 24. The vibratory system of Claim 2, wherein the piezoelectric element and resonator are configured to cause a different selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency provided to the piezoelectric element.
25. The vibratory system of Claim 3, wherein the piezoelectric element and resonator are configured to cause a different selected contacting portion to move in a third elliptical

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motion when excited to simultaneously resonate in at least two vibration modes by a third signal at a third frequency provided to the piezoelectric element.

26. The vibratory system of Claim 2, wherein the selected contacting portion is in contact with the driven element and moving with a defined motion that causes the driven element to vibrate in a manner that creates a plurality of nodes along a length of the driven element, the vibration causing the driven element to move so as to place the selected contact portion at the nearest node.

27. A vibratory system for moving a driven element, the vibratory system excluding the driven element and comprising:

a vibratory element having a driving element comprising one of a piezoelectric element and a magnetoresistive element in driving communication with a resonator that has a selected contacting portion positioned to drivingly engage the driven element during use of the vibratory system;

a resilient element having one end connected to a base and an opposing end connected to the vibratory element to resiliently urge the selected contacting portion against the driven element during use of the vibratory system, at least one of the vibratory element and resilient element being configured to cause the selected contacting portion to move in a first elliptical motion when the vibratory element is excited to simultaneously resonate in at least two vibration modes by a first signal at a first frequency provided to the driving element, the elliptical motion occurring without engagement with the driven element, the motion being of sufficient amplitude to move the driven element during operation of the system, first elliptical motion having a major axis inclined at an angle  $\beta_1$  with respect to a tangent along a direction of motion of a driven element at the selected contacting portion, with the angle  $\beta_1$  being between about 5-85 degrees when the selected contacting portion is drivingly engaging the driven element during operation of the system.

28. The vibratory system of Claim 27, wherein the driving element comprises a piezoelectric element.

29. The vibratory system of Claim 28, wherein the vibratory element is configured to cause the selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency applied to the piezoelectric element so as to cause a different direction of motion of the driven element than with the first frequency.

30. The vibratory system of Claim 28, wherein the resilient element is configured to cause the selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second

frequency applied to the piezoelectric element so as to cause a different direction of motion of the driven element than with the first frequency.

- 5           31. The vibratory system of Claim 28, wherein the vibratory element moves the selected contacting portion in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency applied to the piezoelectric element to cause the driven element to move in a direction opposite the first direction when the selected contacting portion is drivingly engaging the driven element during operation of the system.
- 10          32. The vibratory system of Claim 28, wherein the resonator has a plurality of sidewalls defining a recess in which the piezoelectric element is held in compression, the sidewalls being stressed past their yield strength.
- 15          33. The vibratory system of Claim 32, wherein two opposing sidewalls are curved.
- 20          34. The vibratory system of Claim 31, the second elliptical motion having a major axis inclined at an angle  $\beta_2$  with respect to the axis and with the angle  $\beta_2$  being between about 5-85 degrees when the selected contacting portion is drivingly engaging the driven element during operation of the system.
- 25          35. A vibratory system for moving an object, comprising:  
              a driven element having an engaging portion thereon and mounted on a support, the driven element being movable in at least a first direction;  
              a vibratory element having a driving element that directly converts electrical energy into physical motion, the driving element being in driving communication with a resonator that has a selected contacting portion positioned to drivingly engage the driven element;  
              a resilient element having one end connected to a base and an opposing end connected to one of the vibratory element or the support for the driven element in order to resiliently maintain the selected contacting portion and the engaging portion of the driven element in sufficient contact during operation of the system to move the driven element in the predetermined manner;  
              wherein at least one of the vibratory element and resilient element is configured to cause the selected contacting portion to move in a first elliptical motion when the vibratory element is excited to simultaneously resonate in at least two vibration modes by a first signal at a first frequency provided to the driving element, the motion being sufficient to move the driven element in the predetermined manner, and  
              wherein at least one of the vibratory element and resilient element is configured to cause the selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency

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differing from the first frequency by at least 1 kHz applied to the driving element so as to cause a different motion of the driven element than occurring with the first frequency.

- 5           36. The vibratory system of Claim 35, wherein the driving element is a piezoelectric element and each signal is communicated to the piezoelectric element through the same electrical connection to the piezoelectric element.
- 10          37. The vibratory system of Claim 36, wherein the second elliptical motion has a major axis inclined at an angle  $\beta_2$  with respect to a tangent to the driven element at the selected contacting portion and in the direction of motion of the driven element, the angle  $\beta_2$  being between about 5-35 degrees or 55-85 degrees.
- 15          38. The vibratory system of Claim 36, wherein the opposing end of the resilient member is connected to the support for the driven element.
- 20          39. The vibratory system of Claim 36, wherein the opposing end of the resilient member is connected to the vibratory element.
- 25          40. The vibratory system of Claim 36, wherein the first elliptical motion has a major and minor axis, and the second elliptical motion has a major and minor axis, with the ratio of the major and minor axes being in the range of about 3:1 to 150:1.
- 30          41. The vibratory system of Claim 36, wherein the resilient element is configured to cause the selected contacting portions to move in the second elliptical motion.
42. The vibratory system of Claim 36, wherein the resonator has a plurality of sidewalls defining a recess in which the piezoelectric element is held in compression, the sidewalls being stressed past their yield strength.
43. The vibratory system of Claim 42, wherein two opposing sidewalls are curved.
44. The vibratory system of Claim 36, wherein the resonator comprises an elongated member with the selected contacting portion being located on an edge of a distal end of the member.
45. The vibratory system of claim 36, wherein there are two vibratory elements each having a selected contacting portion resiliently in contact with the driven element.
46. The vibratory system of claim 36, wherein there are at least three vibratory elements each having a selected contacting portion resiliently in contact with the driven element.
47. A vibratory system having at least one source of vibration drivingly connected to vibrate a resonator to amplify the vibration, the resonator having a selected contacting portion located to be engaged with a driven element to move the driven element in at least a predetermined direction, the vibratory system comprising:
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a configuration of resonator and driven element that cooperate to cause the selected contacting portion to move in a first elliptical path when excited by a first electrical signal, the elliptical path having a major axis and minor axis, the major axis being inclined at an angle  $\beta_1$  with respect to a tangent to the driven element at the selected contacting portion in the direction of motion of the driven element, the angle  $\beta_1$  being between about 5-85 degrees.

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48. The vibratory system of Claim 47, wherein the selected contacting portion moves in a second elliptical path when excited by a second electrical signal sufficient to cause a second motion of the selected contacting portion, the second elliptical path having a major axis and minor axis, the major axis being inclined at an angle  $\beta_2$  with respect to a tangent to the driven element at the selected contacting portion and in the direction of motion of the driven element, the angle  $\beta_2$  being between about 5-85 degrees.

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49. The vibration system of Claim 48, wherein the angle  $\beta_1$  is between about 15-25 degrees or 65-75 degrees.

50. The vibration system of Claim 48, wherein the angle  $\beta_2$  is between about 15-25 degrees or 65-75 degrees.

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51. The vibratory system of Claim 48, wherein the ratio of one of the major and minor axis of one of the first and second ellipses is in the range of about 3:1 to 150:1.

52. The vibratory element of Claim 48, wherein the source of vibration comprises a single piezoelectric element.

53. The vibratory element of Claim 48, wherein the source of vibration comprises a plurality of piezoelectric elements each connected to different portions of the resonator.

54. The vibratory element of Claim 48, wherein the source of vibration is contained in an opening in the resonator, and wherein the opening is defined by at least two opposing sidewalls that are curved.

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55. The vibratory element of Claim 48, wherein the source of vibration comprises at least one piezoelectric element contained in an opening in the resonator, and wherein the opening is defined by at least two opposing sidewalls that are curved and stressed beyond their elastic limit while placing the at least one piezoelectric element in compression.

56. The vibratory element of Claim 48, further comprising a resilient support connected to the vibratory element.

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- 5                          57. The vibratory element of Claim 56, wherein the resilient support is required to achieve the first elliptical path.
- 10                        58. A vibratory element having a source of vibration vibrating a resonator to amplify the vibration, the resonator having a selected contacting portion located to be engaged with a driven element to move the driven element in a predetermined direction during use of the vibratory element, the selected contacting portion moving in a first elliptical path when the source of vibration is excited by a first electrical signal at a first frequency, the elliptical path having a major and minor axis which are not aligned with a predominant axis of the vibrating element by a defined angle that varies by less than about 10 degrees when the first frequency varies by about 200 Hz or more on either side of the first frequency.)
- 15                        59. The vibratory element of Claim 58, wherein the source of vibration is a piezoelectric element.
- 20                        60. The vibratory element of Claim 59, wherein the defined angle varies by less than about 5 degrees.
- 25                        61. The vibratory element of Claim 59, wherein the elliptical motion is caused by at least two vibration modes that are superimposed, where at least one of the vibration modes is not a pure longitudinal or pure bending mode.
- 30                        62. The vibratory element of Claim 60, wherein the vibratory element is connected to a resilient support located to resiliently urge the selected contacting portion against a driven element during use of the vibratory element.
- 35                        63. The vibratory element of Claim 58, wherein the source of vibration is a piezoelectric element, and wherein the selected contacting portion moves in a second elliptical motion when the vibrating element is excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency differing from the first frequency by at least 1 kHz applied to the piezoelectric element so as to cause a different motion of the driven element than occurring with the first frequency, and wherein the first and second signals are each communicated to the piezoelectric element through the same electrical connection to the piezoelectric element, the selected contacting portion moving the driven element in a first direction when the source of vibration is driven by the first signal, and moving the driven element in a second direction when the source of vibration is driven by the second signal, and further moves in the first direction when a single sinusoidal signal of a first frequency is applied, and can also move in the first direction when the first frequency is dominant and superimposed with plural sinusoidal signals of different frequencies, the

- second signal not occurring simultaneously with the first signal or being of substantially different amplitude if occurring simultaneously with the first signal.
64. The vibratory element of Claim 58, wherein the elliptical path has a major axis and minor axis, with one of the major or minor axis being inclined at an angle  $\beta$  with respect to a tangent to the driven element at the selected contacting portion and in the direction of motion of the driven element, the angle  $\beta$  being between about 5-85 degrees.
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65. The vibratory element of Claim 59, further comprising a resilient element supporting the vibratory element and contributing to the elliptical motion of the selected contacting portion.
66. A vibratory component for moving a driven element, the vibratory component comprising:  
a piezoelectric vibration source mounted to a resonator to form a vibrating element; the vibrating element having a selected contacting portion located to engage the driven element during use, the selected contacting portion moving in a first elliptical path having a major axis and minor axis when the vibration source is excited by a first electrical signal that causes at least two vibration modes that are superimposed to create the first elliptical path, the first electrical signal being amplified sufficiently to cause at least one off-resonance vibration mode to produce a motion of the selected contacting portion having sufficient amplitude that the resulting elliptical path can move the driven element during use.
67. The vibratory component of Claim 66, further comprising a resilient support connected to the vibration source, and wherein the ratio of the major axis to the minor axis is about 5:1 or greater.
68. The vibratory component of Claim 66, with one of the at least two vibration modes being excited off-resonance by coupling to another of the resonance modes with the coupling arising from the geometry of at least one of the vibrating element and a resilient support for the vibrating element.
69. A vibratory component for moving a driven element in a first direction, the vibratory component comprising:  
a vibration source mounted to a resonator to form a vibrating element; the vibrating element having a selected contacting portion located to engage the driven element during use, the selected contacting portion moving in a first elliptical path having a major axis and minor axis when the vibration source is excited by a first electrical signal that causes at least two vibration modes that are superimposed to create the first elliptical path, at

- least one of the vibration modes is other than a pure longitudinal mode and other than a pure bending mode, the elliptical motion having a major axis and minor axis, one of which is aligned with a tangent at the selected contacting portion that is aligned with the first direction.
- 5        70. The vibratory component of Claim 69, further comprising a resilient element connected to the vibrating element.
- 10      71. The vibratory component of Claim 69, wherein the vibration source comprises a piezoelectric element excited by a second electrical signal that causes at least two vibration modes that are superimposed to create a second elliptical path at the selected contacting portion, at least one of the vibration modes resulting from the second electrical signal being other than a pure longitudinal mode and other than a pure bending mode, the second elliptical motion being in a direction different from the direction of the first elliptical motion.
- 15      72. A vibratory system for moving a driven element, comprising:  
                a driven element movable in at least a first direction;  
                a vibration source mounted to a resonator to form a vibrating element; the vibrating element having a selected contacting portion located to engage and move the driven element, the selected contacting portion moving in a first elliptical path, a longitudinal axis of the vibrating element being inclined at an angle  $\alpha$  to a tangent to the driven element in the first direction at the selected contacting portion, the angle  $\alpha$  being between about 10 and 80 degrees when the selected contacting portion is drivingly engaging the driven element;
- 20          a signal generator providing a first signal at a first frequency to the vibrating element to cause the elliptical motion;
- 25          a resilient mount connected to the vibrating element.
73. The vibratory system of Claim 72, wherein the vibration source comprises a piezoelectric element.
- 30      74. The vibratory system of Claim 73, wherein at least one of the vibrating element and resilient mount are configured to cause the selected contacting portion to move in a second elliptical motion when excited to simultaneously resonate in at least two vibration modes by a second signal at a second frequency provided to the piezoelectric element.
75. A vibratory component for moving a driven element in at least two directions, the vibratory component comprising:

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- a vibration source mounted to a resonator to form a vibrating element; the vibrating element having a selected contacting portion located to engage the driven element during use, the selected contacting portion moving in a first elliptical path having a major axis and minor axis when the vibration source is excited by a first electrical signal to produce at least two vibration modes that are superimposed to create the first elliptical path and move the selected contacting portion a predetermined distance in a first direction, the selected contacting portion moving in a second elliptical path having a major axis and minor axis when the vibration source is excited by a second electrical signal to produce at least two vibration modes that are superimposed to create the second elliptical path and move the selected contacting portion a predetermined distance in a second direction, at least one of the vibration modes is other than a pure longitudinal mode and other than a pure bending mode, the first and second elliptical motions each having a major axis and minor axis, at least one of the axis of the first and second elliptical motions being alignable with the driven element during use sufficiently to move the driven element during use in two different motions, the second electrical signal differing from the first electrical signal by about 200 Hz or more on either side of the first electrical signal.
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76. The vibratory component of Claim 75, further comprising a resilient element connect to the vibratory element and being used to achieve at least one of the first and second elliptical motions.
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77. The vibratory component of Claim 76, further comprising the driven element and wherein the selected contacting portion is resiliently urged by the resilient element against the driven element.
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78. The vibratory component of Claim 76, wherein the source of vibration is a piezoelectric element.
79. The vibratory component of Claim 77, wherein the first and second frequencies differ by 2.5 kHz, or more.
80. A vibratory system for moving a driven element, comprising:  
a driven element moving in a first and second direction;  
a vibratory element in driving communication with a resonator that has a selected contacting portion positioned to drivingly engage the driven element during use of the vibratory system to move the driven element in a first and second direction, the vibratory element moving the selected contacting portion in a first and second elliptical paths each having a major and minor axis, at least one of the major and minor axes not coinciding with the direction of motion resulting from the elliptical path with which the axis is associated, the vibrating element resonating when excited by a first signal having a first
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frequency to cause the first elliptical path to move the driven element in the first direction, and further resonating when excited by a second signal having a second frequency to cause the second elliptical path to move the driven element in the second direction, each signal being communicated to the vibratory element through the same electrical connection to the vibratory element.

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81. The vibratory system of Claim 80, wherein the first and second elliptical paths each have a major axis and a minor axis, with one of the axis inclined at an angle  $\beta$  with respect to a tangent along the first direction of motion of the driven element at the selected contacting portion, with the angle  $\beta$  being between about 5-80 degrees when the selected contacting portion is drivingly engaging the driven element during operation of the system.

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82. The vibratory system of Claim 80, wherein the major axes of the first and second elliptical paths are inclined at angle  $\beta_1$  and  $\beta_2$ , respectively, with respect to a tangent along the first direction of motion of the driven element at the selected contacting portion, with each of the angles  $\beta_1$  and  $\beta_2$ , being greater than 5 degrees.

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83. The vibratory system of Claim 80, further comprising a resilient element having one end connected to a base and an opposing end connected to the vibratory element to resiliently urge the selected contacting portion against the driven element during use of the vibratory system.

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84. The vibratory system of Claim 83, wherein the vibratory element comprises at least one piezoelectric element.

85. The vibratory system of Claim 83, wherein the vibratory element comprises a single piezoelectric element.

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86. A method of configuring a vibratory system having a vibrating element with a selected contacting portion drivingly engaging a driven element to move the driven element by moving the selected contacting portion in a first elliptical motion, comprising:

analyzing that elliptical motion in a localized coordinate system in which at least one of the major and minor axes of the elliptical motion are not aligned with a predominant axis of the vibrating element;

varying the system design to incline at least one of the elliptical axes relative to a tangent to the driven element in the direction of motion at the selected contacting portion to better align the at least one axis relative to the tangent by an amount sufficient to achieve acceptable motion of the driven element in at least one direction, the inclination

- being achieved by at least one of altering the elliptical motion or altering the relative orientation of the vibrating element and the driven element; and  
5 maintaining that inclination during operation of the vibrating system.
87. The method of Claim 86, wherein the localized coordinate system is relative to the tangent, with the angle of inclination of the major axis of the first elliptical motion being designated by an angle  $\beta_1$  which is greater than 5 degrees, and with the vibrating element and the driven element being inclined relative to each other by an angle  $\alpha$  that is greater than about 5 degrees.
- 10 88. The method of Claim 86, wherein the system includes a vibrating element having an elongated shape with a longitudinal axis, with the predominant axis being parallel to the longitudinal axis or an axis orthogonal to the longitudinal axis, and having the selected contacting portion moving in a second elliptical motion to move the driven element in a second direction, and further comprising:  
15 analyzing that second elliptical motion in a localized coordinate system in which at least one of the major and minor axes of the second elliptical motion are not aligned with a predominant axis of motion of the vibrating element;  
20 varying the system design to incline at least one of the second elliptical axes relative to a tangent to the driven element in the second direction at the selected contacting portion to more closely align the at least one axis of the second elliptical motion with the tangent in the second direction by an amount sufficient to achieve acceptable motion of the driven element in the second direction; and  
25 maintaining that inclination of the second elliptical axis during use of the system.
89. The method of Claim 88, wherein the localized coordinate system is relative to the tangent, with the angle of inclination of the major axis of the first elliptical motion being designated by an angle  $\beta_1$ , and with the vibrating element and the driven element being inclined relative to each other by an angle  $\alpha$  that is greater than about 5 degrees and with the angle of inclination of the major axis of the second elliptical motion being designated by an angle  $\beta_2$ , with at least one of  $\beta_1$  and  $\beta_2$  being greater than 5 degrees.
- 30 90. The method of Claim 88, wherein the vibratory element is resiliently mounted to a base, and wherein the orientation of at least one of the first and second elliptical axes is a compromise that is selected to achieve less than optimum motion of the driven element in one direction in order to improve the motion of the driven element in the other direction.

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- 5        91. The method of Claim 86, further comprising, configuring at least one of the vibratory element and a resilient support for the vibratory element to cause the resonator to vibrate in two modes of sufficient amplitude and phase that the selected contacting portion moves in the first elliptical path when the vibratory source is excited by a first signal at a first frequency provided to the vibration source.
- 10      92. The method of Claim 88, further comprising configuring at least one of the vibratory element and a resilient support for the vibratory element to cause the resonator to vibrate in two modes of sufficient amplitude and phase that the selected contacting portion moves in the first elliptical path when the vibratory source is excited by a first signal at a first frequency provided to the vibration source, and to cause the resonator to vibrate in two modes of sufficient amplitude and phase that the selected contacting portion moves in the second elliptical path when the vibratory source is excited by a second signal at a second frequency provided to the vibration source.
- 15      93. The method of Claim 92, wherein the vibratory element is selected to comprise a piezoelectric element.
- 20      94. The method of Claim 93, comprising the further step of driving the vibration of the vibratory element by use of an inductive coil mounted on the piezoelectric element and acting in cooperation with the capacitance of the piezoelectric element to form an L-C driving circuit.
- 25      95. A method of configuring a vibratory system for moving a driven element that is supported to allow the driven element to move in a predetermined manner, the system having a selected contacting portion of a vibratory element periodically engaging the driven element to move the driven element, the vibratory element being caused to vibrate by a vibration source that converts electrical energy directly into physical motion, the vibratory element comprising the vibration source mounted in a resonator with the selected contacting portion being on the resonator, comprising:  
                resiliently urging one of the selected contacting portion and the driven element against the other to place the selected contacting portion in resilient contact with the driven element;
- 30                       defining a desired elliptical motion of the selected contacting portion to produce a desired movement of the driven element;  
                configuring at least one of the vibratory element and apparatus performing the resilient urging in order to cause the resonator to vibrate in at least two modes of sufficient amplitude and phase that the selected contacting portion moves in an elliptical path when the vibratory source is excited by a first signal at a first frequency provided to

the vibration source, the elliptical path being sufficiently close to the desired elliptical motion to achieve an acceptable motion of the driven element, at least one of the at least two vibration modes being selected to not include a pure longitudinal or pure bending mode of the resonator to produce the first elliptical motion; and

5 orientating the vibratory element so that the elliptical path aligns with the driven element by an amount sufficient to achieve the desired motion of the driven element.

96. A method of configuring a vibratory system for moving a driven element that is supported to allow the driven element to move in a predetermined manner, the system

10 having a selected contacting portion of a vibratory element periodically engaging the driven element to move the driven element, the vibratory element being caused to vibrate by a vibration source that converts electrical energy directly into physical motion, the vibratory element comprising the vibration source mounted in a resonator with the selected contacting portion being on the resonator, comprising:

15 resiliently urging one of the selected contacting portion and the driven element against the other to place the selected contacting portion in resilient contact with the driven element;

defining a desired first elliptical motion of the selected contacting portion to produce a desired movement of the driven element;

20 configuring at least one of the vibratory element and apparatus performing the resilient urging in order to cause the resonator to vibrate in at least two modes of sufficient amplitude and phase that the selected contacting portion moves in a first elliptical path when the vibratory source is excited by a first signal at a first frequency provided to the vibration source, the elliptical path being sufficiently close to the desired first elliptical motion to achieve an acceptable motion of the driven element;

25 orientating the vibratory element so that the first elliptical path aligns with the driven element by an amount sufficient to achieve the desired motion of the driven element;

30 defining a second desired elliptical motion of the selected contacting portion to produce a second desired movement of the driven element;

configuring at least one of the vibratory element and the apparatus achieving the resilient urging in order to cause the resonator to vibrate in two modes of sufficient amplitude and phase that the selected contacting portion moves in a second elliptical path when the vibratory source is excited by a second signal at a second frequency provided to the vibration source, the second elliptical path being sufficiently close to the second

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desired elliptical motion to achieve an acceptable second movement of the driven element; and

electrically connecting a signal generator to the vibratory element, the signal generator producing the first and second signal, each signal being communicated to the vibratory element through the same electrical connection to the vibratory element, the selected contacting portion moving the driven element in the first direction when the vibratory element is driven by the first signal, and moving the driven element in the second direction when the vibratory element is driven by the second signal, and further moves in the first direction when a single sinusoidal signal of a first frequency is applied, and can also move in the first direction when the first frequency is dominant and superimposed with plural sinusoidal signals of different frequencies, the second signal either not occurring simultaneously with the first signal or being of substantially different amplitude if it occurs simultaneously with the first signal.

5 97. The method of Claim 96, wherein the vibration source is selected to comprise a piezoelectric element.

10 98. The method of Claim 97, wherein the resonator is configured to cause the desired motion of the selected contacting portion.

15 99. The method of Claim 97, comprising configuring the resonator to have a vibration mode producing a node on the resonator during operation of the resonator at the first frequency, and further comprising connecting a resilient mounting to the vibratory element at the node, and resiliently urging the vibratory element against the driven element during operation of the resonator.

20 100. The method of Claim 97, further comprising placing the piezoelectric element in compression in the resonator during operation of the system by press-fitting the piezoelectric element into an opening in the resonator.

25 101. The method of Claim 100, further comprising placing the piezoelectric element in compression by stressing walls of the resonator past their yield point but not past their ultimate strength point.

30 102. The method of Claim 97, further comprising interposing the resilient element a base and the vibratory element to resiliently urge the vibratory element against the driven element during excitation at the first frequency.

35 103. The method of Claim 97, wherein the resonator has a longitudinal axis and the driven element has a longitudinal axis, and further comprising placing the two axes at an angle of between about 10 and 80 degrees when the selected contacting portion is drivingly engaging the driven element.

104. The method of Claim 97, comprising using the piezoelectric element to generate a vibratory signal and detecting that vibratory signal by a sensor in placed in communication with the driven element, and using the time between the generation and receipt of the vibratory signal to determine the position of the driven element relative to the vibrating element.
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105. The method of Claim 97, further comprising configuring at least one of the piezoelectric element and resonator to cause a different selected contacting portion to move in a third elliptical motion when excited to simultaneously resonate in at least two vibration modes by a third signal at a third frequency provided to the piezoelectric element.
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106. The method of Claim 105, further comprising configuring the driven element to vibrate in a manner that creates a plurality of nodes along a length of the driven element with the vibration causing the driven element to move so as to place the selected contact portion at the nearest node and exciting the piezoelectric element at a frequency that causes the vibration to create the plurality of nodes.
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107. A method for moving objects using vibratory motors having a vibration source placed in a resonator, comprising:
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- moving a selected contacting portion of a resonator in a first elliptical motion in a first direction by configuring one of the resonator or a resilient support for the resonator in order to simultaneously vibrate in at least two modes to cause the first elliptical motion of the selected contacting portion when a first electrical signal at a first frequency is applied to the vibration source;
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- selecting at least one of the two vibration modes to be off-resonance, the first electrical signal being either selected to have sufficient amplitude and phase, or being amplified sufficiently, to cause the at least one off-resonance vibration mode to produce a predetermined motion of the selected contacting portion having sufficient amplitude that the resulting elliptical path can move the driven element during use;
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- moving the selected contacting portion a second elliptical motion in a second direction different from the first direction by configuring one of the resonator or the resilient support for the resonator in order to simultaneously vibrate in at least two modes to cause the second elliptical motion of the selected contacting portion when a second electrical signal at a second frequency is applied to the vibration source; and
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- electrically connecting a signal generator to the vibratory element, the signal generator producing the first and second signals, each signal being communicated to the vibratory element through the same electrical connection to the vibratory element, the

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selected contacting portion moving the driven element in the first direction when the vibratory element is driven by the first signal, and moving the driven element in the second direction when the vibratory element is driven by the second signal, and further moving in the first direction when a single sinusoidal signal of a first frequency is applied, and can also move in the first direction when the first frequency is dominant and superimposed with plural sinusoidal signals of different frequencies, the second signal either not occurring simultaneously with the first signal or being of substantially different amplitude if it occurs simultaneously with the first signal.

10 108. The method of Claim 107, further comprising resiliently urging the selected contacting portion into resilient contact with a driven element to move the driven element.

15 109. The method of Claim 107, further comprising generating a vibratory signal with the vibration source and transmitting that signal through the driven element to a location where it is detected by a detector, and monitoring the time between generating and detecting that signal in order to determine a relative position of the driven element.

20 110. The method of Claim 107, further comprising selecting a piezoelectric element for the vibration source and placing that piezoelectric element in compression by press-fitting it into an opening in the resonator.

111. The method of Claim 110, wherein the opening is defined by at least two opposing walls that are stressed beyond their elastic limit when the piezoelectric element is press-fit into the opening.

112. The method of Claim 111, wherein the walls are selected to be curved.

25 113. A method for moving a driven element by a vibratory element having a predominant axis and having a selected contacting portion located to be engaged with the driven element to move the driven element along a driven path during use, the selected contacting portion moving in a first elliptical path, comprising:

30 selecting the elliptical path to have a major and minor axis which are not aligned with a predominant axis of the vibrating element by a defined angle that varies by less than about 10 degrees when the first frequency varies by about 200 Hz or more on either side of the first frequency;

configuring at least one of the vibratory element and a resilient support for the vibratory element to generate the selected elliptical path; and

exciting the source of vibration by a first electrical signal at a first frequency selected to generate the elliptical path.

114. The method of Claim 113, further comprising selecting the source of vibration to be a piezoelectric element.

5 115. The method of Claim 113, wherein the elliptical motion is caused by at least two vibration modes that are superimposed, where at least one of the vibration modes is selected to be other than a pure longitudinal or pure bending mode.

10 116. The method of Claim 113, wherein one of the major or minor axis is inclined at an angle  $\beta$  with respect to a tangent to the driven element at the selected contacting portion and in the direction of motion of the driven element, the angle  $\beta$  being selected to be between about 5-85 degrees.

117. The method of Claim 113, further comprising providing a vibratory element to have a rod-shape with the selected contacting portion being located at a distal end of the rod-shaped vibrating element.

15 118. A method for moving a driven element by a vibratory element having a source of vibration that converts electrical energy directly to physical motion, the vibratory element having a predominant axis and having a selected contacting portion located to be engaged with the driven element at an angle  $\alpha$  selected to move the driven element along a driven path during use, comprising:

20 exciting the vibratory element with a first electrical signal to vibrate at a first frequency in a first vibration mode having sufficient motion along a first axis that the selected contacting portion moves along a first path to cause an impact drive of the driven element, at least one of a resonator for the vibrating element and a resilient mounting system for the vibrating element being provided and configured to achieve the first path;

25 exciting the vibratory element with a second electrical signal to vibrate at a second frequency in a second vibration mode having sufficient motion along a second axis that the selected contacting portion moves along a second path to move the driven element, at least one of the resonator and resilient mounting system for the vibrating element being provided and configured to achieve the second path.

30 119. The method of Claim 118, wherein the vibratory element is selected to comprise a piezoelectric source of vibration.

120. The method of Claim 118, wherein at least one of the first and second paths comprises an elliptical path having an aspect ratio of over 30:1.

35 121. The method of Claim 118, wherein one of the first and second paths comprises an elliptical path having an aspect ratio of over 30:1.

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122. The method of Claim 118, wherein one of the first and second paths comprises an elliptical path having an aspect ratio of under 30:1.
123. The method of Claim 118, wherein one of the first and second paths comprises a purely longitudinal motion along the predominant axis.
- 5        124. A vibratory system for moving a driven element, the system having a source of vibration that converts electrical energy directly into physical motion and causing a resonator with a selected contacting portion to drivingly engage a driven element, the selected contacting portion maintaining sufficient contact with the driven element to move the driven element during operation of the system, the system comprising:
- 10      a signal generator electrically connected to the source of vibration, the signal generator producing a first and second signal, each signal being communicated to the vibration source through the same electrical connection to the source of vibration, the selected contacting portion moving the driven element in a first direction when the source of vibration is driven by the first signal, and moving the driven element in a second direction when the source of vibration is driven by the second signal, and further moves in the first direction when a single sinusoidal signal of a first frequency is applied, and can also move in the first direction when the first frequency is dominant and superimposed with plural sinusoidal signals of different frequencies, the second signal either not occurring simultaneously with the first signal or being of substantially different amplitude if it occurs simultaneously with the first signal.
- 15      125. The vibratory system of Claim 124, wherein the source of vibration comprises a piezoelectric element, the system further comprising a resilient mount on at least one of the resonator and driven element, at least one of the resonator and resilient mount being configured to cause the motion of the driven element in at least one of the directions.
- 20      126. The vibratory system of Claim 124, wherein the source of vibration comprises a piezoelectric element, and wherein the electrical connection with the piezoelectric element comprises only two electrical wires each having one end connected to the signal generator and an opposing end connected to the piezoelectric element.

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